Department of Physics

Lab 5: Magnetism

Earth's Magnetic Field

The Earth's magnetic field has a direction, as must all magnetic fields. Measuring the field while orienting the measuring probe in different directions will change how much of the field is measured along that direction.
Because the Earth itself creates a magnetic field similar to the field that would be produced by a large bar magnet buried way down at the center of the Earth, the field lines this far north of the equator have substantial vertical components (whereas field lines are pretty much parallel to the Earth's surface at the equator). The building can also distort field lines due to the large amount of structural material made of iron, causing the directions of the field lines to be noticeably different from textbook specification.
Note that the Vernier probe gives measurements in Tesla, the SI unit. Another common unit of magnetic field strength is Gauss; 1 Gauss $= 0.1$ milliTesla.

Apparatus

1. Magnetic Field Probe
2. 400 turn solenoid
3. Power supply up to 0.3 A
4. Logger Pro Ammeter
5. Logger Pro Software and box

Procedure

The following steps should help you to find the directionality of the Earth's magnetic field and yield a numerical value for the strength of the field.

1. Connect the Magnetic Field probe and ensure that it is set to the **0.3 mT** sensitivity setting if prompted by Logger Pro, select `Use Sensor Setting`.

2. Collect data and sweep the probe in one plane until you find the maximum, then sweep in the other plane until you find the overall maximum reading. At this point you have found the direction and angle of the earth's magnetic field in the room. Once you have found the maximum, sweep the probe 180° until you have a clear minimum reading. The difference between min and max values is **two times** the value of the Earth's field strength.

Question 1

What is your measured magnetic field strength and direction? How does this compare to a published value of 52 microTesla?

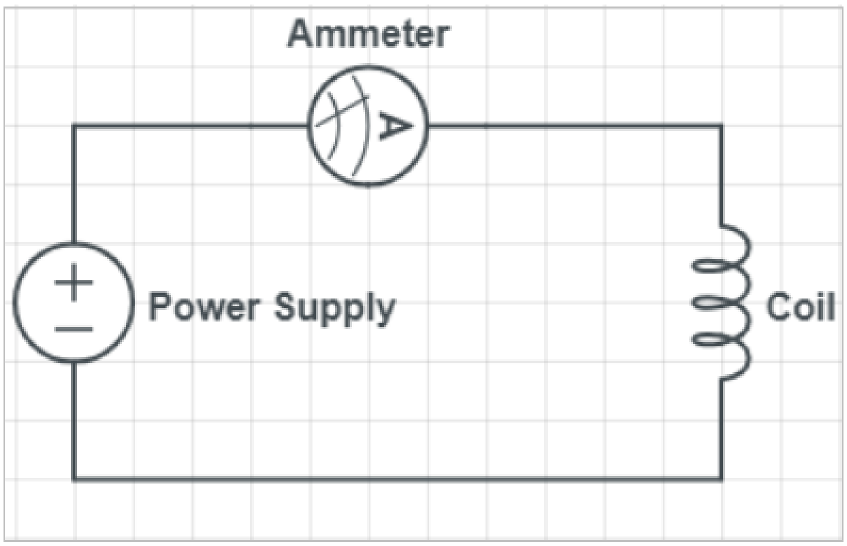

Figure 1: The circuit we will be using here

The Magnetic Field of a Solenoid

A solenoid is a long coil of wire wrapped in many turns in a cylindrical fashion. When current passes through the solenoid, it creates a magnetic field inside. The magnetic field produced inside a solenoid depends upon the current and number of turns per unit length. In an ideal, infinitely long, solenoid, the magnetic field inside is constant along the length. In this experiment we use a solenoid of finite length, will measure the magnetic field in and outside the solenoid, and compare data with calculated values for an ideal solenoid.

Data Collection

- Create a table to collect data using the template below as a guide.

Current ( )	Distance ( )	Magnetic field ( )	Magnetic field Uncertainty ( )

- With the power supply off, hook up your solenoid, current meter and power supply as shown in Figure 1.
- Make sure the sensor is on the **6.4 mT** setting, if prompted by Logger Pro, select `Use Sensor Setting`.
- Arrange your solenoid, magnetic filed probe and ruler into position to the position that you will be taking data in.
- Once you are ready to take data, and with the power supply off, zero both your current probe and magnetic filed sensors.
- Set power supply to run 0.3 amps through the solenoid as shown by the current meter, use small adjustments as the current will rise fast.
- Record the magnetic field vs distance starting from the center of solenoid, move the probe out from the center in 5mm increments. Start at center and go to 70mm away from center.
- For each position collect magnetic field data for at least 5 second and record the mean and Standard deviation values in your table.

Data Analysis

The equation for the magnetic field in an infinitely long ideal solenoid is,

$$B = \mu_0 n I, \tag{1}$$

where B is the magnetic filed in Teslas, μ_0 is the magnetic permeability of free space 4π x 10^{-7}, n is the turn density of the solenoid $\left(\frac{N}{L} \text{ or } \frac{Number of Turns}{meter} \right)$ and I is the current through the solenoid.

- Using the equation above, calculate the magnetic field inside an ideal solenoid with the same turn density as the one at your lab station.
- Create a new Logger Pro File to use for graphing your data.
- You will need to create 4 manual columns: magnetic field, magnetic field uncertainty, distance, and theoretical magnetic field.
- Add your data to each of these columns (you can use the same theoretical value for all of the entires in that column).
- Set the error bars for the magnetic field measurements to the column for uncertainty.
- Set the error bars for the distance to a constant uncertainty that you estimate based on your measurement device and technique
- Make a new page in Logger Pro and insert a new graph, make the y-axis show both the magnetic field data as well as the theoretical magnetic field data, the x-axis should show you distance measurements.
- Multiple data columns may be added to the y-axis by double clicking the graph to access the graph options window.

How to make a graph in LoggerPro

1. Disconnect your sensors and open a new Logger Pro file (please reconnect the sensors for the next students when you are finished)
2. Create 4 new manual columns in Logger Pro `Data > New Manual Column` for you to enter the data that you collected. The new manual columns could be named: "resistor voltage", "resistor voltage" uncertainty", "resistor current" and "resistor current uncertainty"; etc.
3. Create a new page `Page > Add Page` and insert a table using `Insert > Table`, make sure that the table is large enough to show all of your new columns. You can now enter your collected data into the appropriate columns.
4. Double click on the top of each voltage column, go to the settings tab and set your voltage uncertainty column as the source of error bars in the bottom right of the screen as shown in Figure 2. Do the same with each current column.

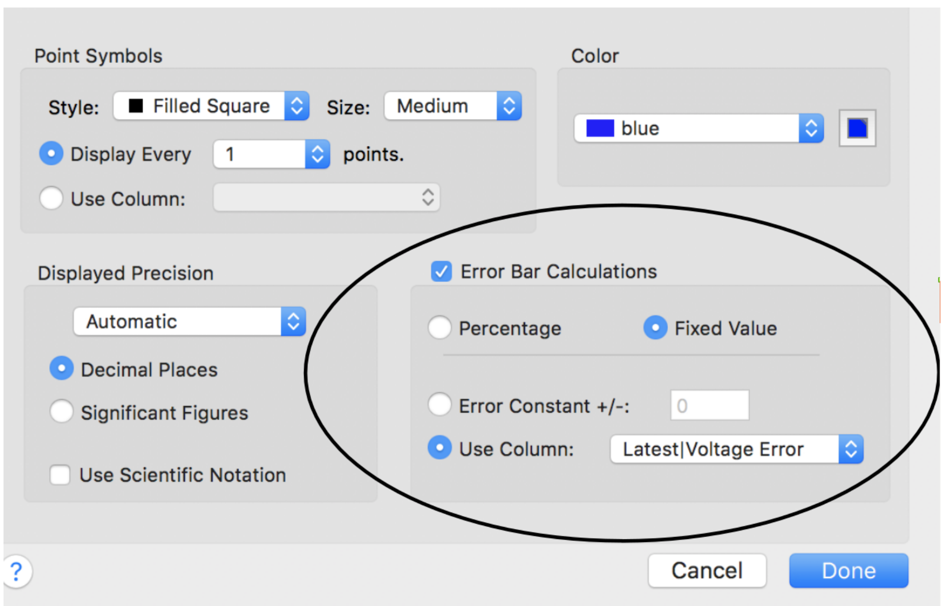

Figure 2: Table options dialog, check the "Error Bar Calculations" and "Fixed Value Box". Then select the manual column that corresponds with your measured uncertainties for that column of data.

5. Create another new page and insert a graph. Set the graph axes to be Voltage on the y-axis and Current on the x-axis for one of your components. Make sure that your error bars are visible on the screen and change the title of the graph to correspond with the component that your data is from.
6. Add a trend line if required
   (a) To perform a linear fit on each graph where you think the data may be linear in nature,
      i. Highlight the part of the graph that is linear.
      ii. Select 'linear fit'
      iii. Move the text box into a position that does not cover the data points. Show the uncertainties in the fit by right clicking on the box, selecting "**Linear fit options**" and checking the box marked "**Show Uncertainty**" as shown in Figure 3.

(b) To add a polynomial trend line,

   i. Highlight the part of the graph that you wish to fit.
   ii. Select 'Analyze' then 'Curve Fit'.
   iii. Select the equation you wish to apply to your curve.
   iv. Select 'Automatic' and then 'Try Fit'. That will change the parameters of your fit values. Once the fit looks good please select 'OK'.
   v. Then right click on the information box on the graph and select 'Fit Options', and select 'Show Standard Error'.

7. Copy the graph in to the results section of this file below, one for each component tested (**a total of 2 graphs**). Remember to format the figures correctly and include a caption as described in the review below.

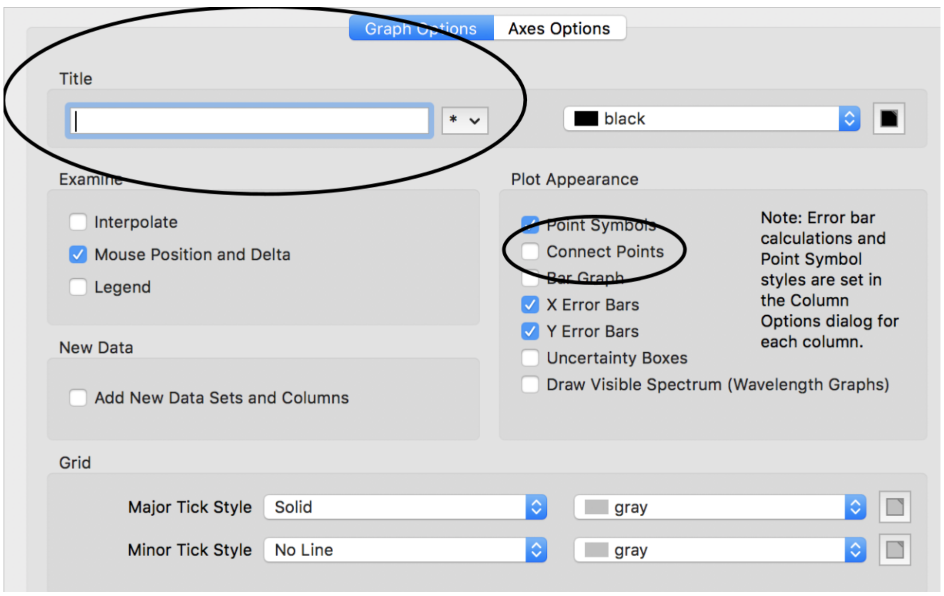

Figure 3: Graph options dialog, add a title, check the "Point Symbols" box and **uncheck** the "Connect Points" box.

In paragraph form where appropriate, complete the following sections making sure to answer the questions posed in each section as a guideline.

Question 2 **Lab Modus Operandi**

Communicate the steps that you took when collecting and analyzing your data.

Pretend you are writing this so a fellow student that missed this lab could take and analyze the data using only this section. For example, you do not need to tell them to press start in Logger Pro or open the program, but you would want to tell them what sensors you used to collect data and if there are any special settings that you used. (3-4 sentences)

Question 3 **Data Analysis**

- *Include your calculation, with values, for the theoretical magnetic field value.*

Question 4 **Results**

- *Describe how the magnetic field changed or didn't change over distance for both your measured values as well as your theoretical values. Use the actual numbers and references to your figures when possible.*
- *What conclusions can you make about the magnetic field of a solenoid based on your experiments today? Do your results make sense based on what you know of physics? If not, what might be a reason for the discrepancy?*

Question 5 **Conclusion**

- *Please reflect on what we worked through today, and write 3-4 sentences on what you think you learned during this lab.*
- *What further questions do you have about this lab? How would you test those questions if you had the ability to do so?*

Question 6 *Graph and Data Checklist: You should have written an answer for each section highlighted by the gray boxes. Make sure that you used complete sentences and that your conclusions match your results. You should also have* ***1 table*** *and* ***1 graph*** *showing your data.* [a]

[a] Check with your Lab Instructor if you can use Excel for the plotting

Review

How to make a graph in LoggerPro

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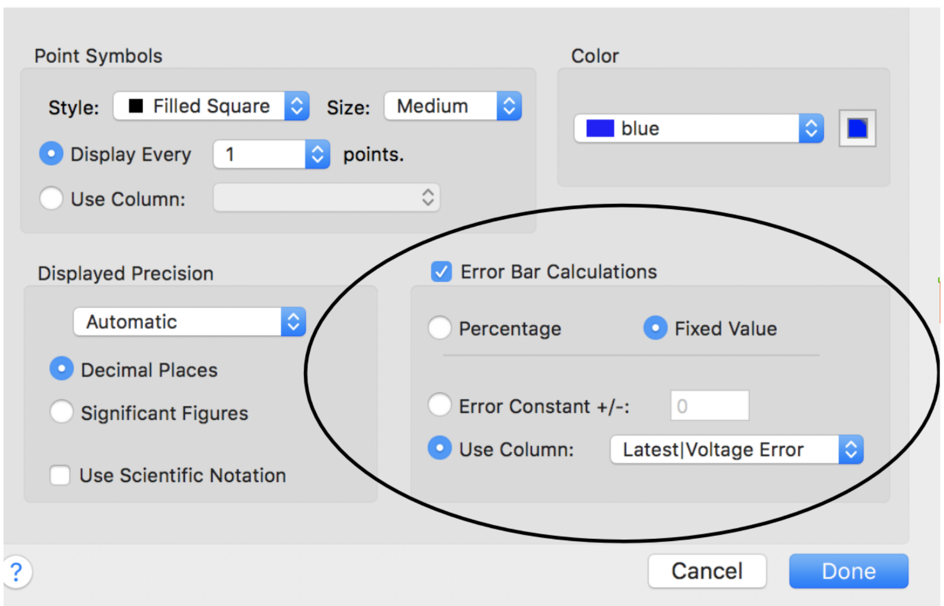

Figure 4: Table options dialog, check the "Error Bar Calculations" and "Fixed Value Box". Then select the manual column that corresponds with your measured uncertainties for that column of data.

5. Create another new page and insert a graph. Set the graph axes to be Voltage on the y-axis and Current on the x-axis for one of your components. Make sure that your error bars are visible on the screen and change the title of the graph to correspond with the component that your data is from.

6. Add a trend line if required

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      i. Highlight the part of the graph that is linear.

      ii. Select 'linear fit'

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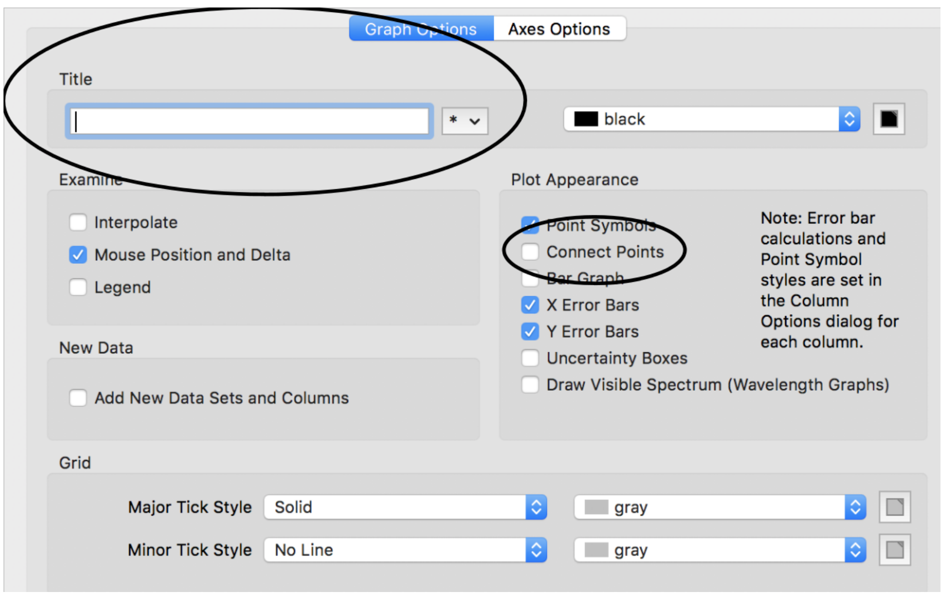

Figure 5: Graph options dialog, add a title, check the "Point Symbols" box and **uncheck** the "Connect Points" box.

Once you have collected all your data, and before you leave for the day please make sure to

1. **Turn off power supplies.** You may leave them plugged into the walls, but make sure they are off.
2. Leave Voltage and Current probes (Ammeter and Voltmeter's) plugged in to the logger pro, but please make sure none of the wires are touching the ground. Please also leave your green box plugged into your computer and at your station.
3. Unhook your wires from your circuit boards, and place the circuit board back in their white boxes.
4. Put wires back in the white box, or if there is no room in the white box then put them in the communal wire box that is near the front of each room.
5. If you used a capacitor and attached it to the board **please do not remove it from the board after connecting it**. Too much connecting and unconnecting will weaken or break the wires eventually.

The Figures and Caption Rules

There are a few very important aspects to creating a proper figure and caption. If you follow these rules, not only will you get points on your physics lab grades, you will impress your instructors and peers in the future.

The Caption

- The caption should start with a label so you can reference the figure from other places in your paper/report. For this course you should use "Figure 1", "Figure 2", etc.
- The caption should allow the figure to be standalone, that is to say, by reading the caption and looking at the figure, it should be clear what the figure is about and why it was included without reading the whole paper.
- The caption should contain complete sentences and be as brief as possible while still conveying your information clearly (this is not always easy).
- Please add captions to your tables as well, otherwise we will not know what we are looking at.

The Figure

- **Make sure that the resolution is high enough to not be pixelated at its final size.**
- Check that any text is readable at the final size (Using a smaller graph in Logger Pro will cause the text to be larger in relation to the graph when inserted into another program).
- For graphs, ensure that the axes are labeled (including units) and that there is a legend if you have multiple data sets on the same graphs.

Tables

- The first row of the table should be a header, where each item is labeled with what is contained in that row. If it is a physical measurement it should have the correct units.
- For tables include a short caption of what is contained in the table, or what was examined.
- The caption should start with a label so you can reference the figure from other places in your paper/report. For this course you should use "Table 1", "Table 2", etc. For an example of a good table caption please see Figure 4.

Table 1. Baseline characteristics of study participants

Variables	Intervention group (n=14)	Control group (n=15)
Women (no [%])	7 (50)	5 (33)
Median age (range)	22.0 (19 – 58)	21.0 (18 – 70)
First winter in icy conditions (no [%])	—	1 (7)
Previous falls on ice (no [%])	8 (57)	11 (73)
≥ 1 fall this winter (no [%])	4 (29)	7 (50)
Injury from fall this winter (no [%])	1 (7)	—
Time been walking this route (no [%]):		
<6 months	3 (21)	2 (13)
6–12 months	9 (64)	9 (60)
>12 months	2 (14)	4 (26)

Figure 6: An example table from the paper Lianne Parkin, Sheila M Williams, and Patricia Priest, "Preventing Winter Falls: A Randomised Controlled Trial of a Novel Intervention" 122, no. 1298 (2009): 9.

Human Error

Humans can often be a source of error, but describing one's total error as 'human error' does little to illuminate the subject. Humans can contribute error to a system, but it is not their mere presence, often, that causes that error. That error is contributed by a specific action, or lack of action of the operator and you should always be specific. If we ask for why there might be error in a system, and someone responses with just human error without explaining what, specifically, that answer will not receive credit.

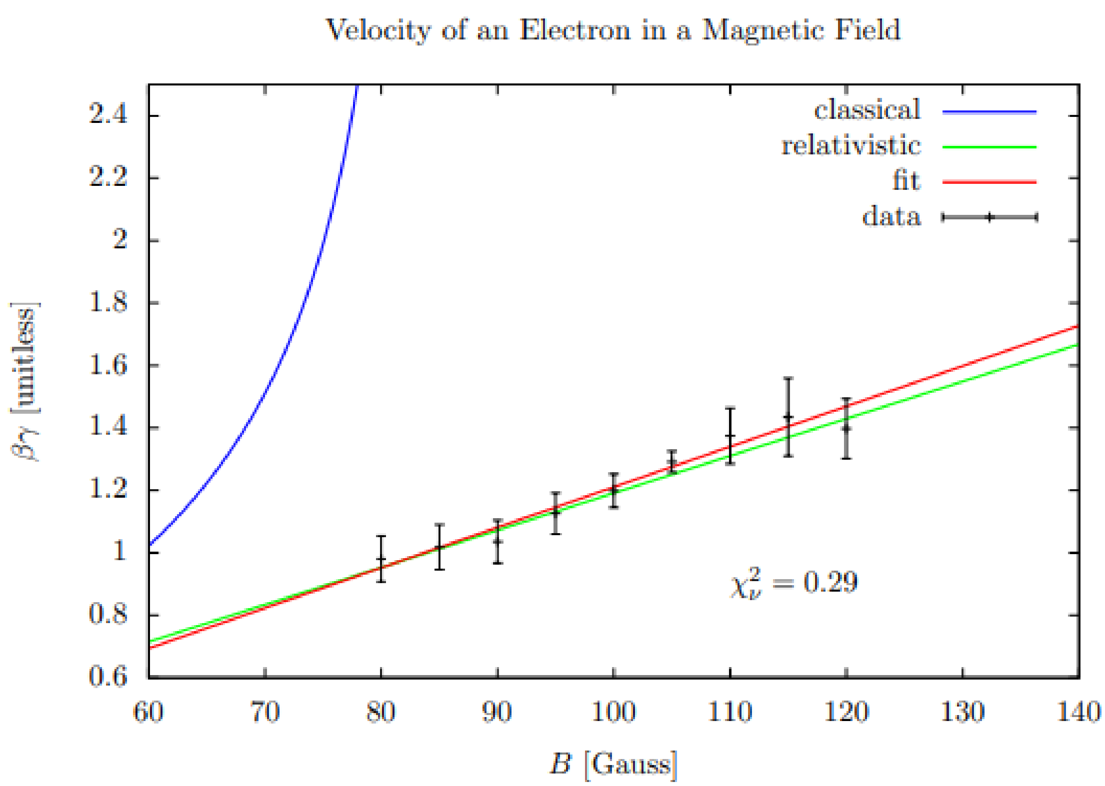

Figure 7: Example of a good figure with excellent error bars and a label. Figure from Philip Ilten of University College Dublin [1].

Python

According to IEEE Spectrum, Python is the most popular programming languages. Python is a free, general purpose, cross discipline programming language that has moved to the forefront of many disciplines.

If you decide to use Python your TA's will help you troubleshoot your code. While they might be able to help you troubleshoot when you use a different program or code, be aware of the fact that they are not familiar with all programming codes. There are many languages (R, Matlab, Opal, Julia, etc.) out there that are just as useful as Python, but we have chosen to use Python here. You may use any programming language you wish, but not Excel or Google Sheets.

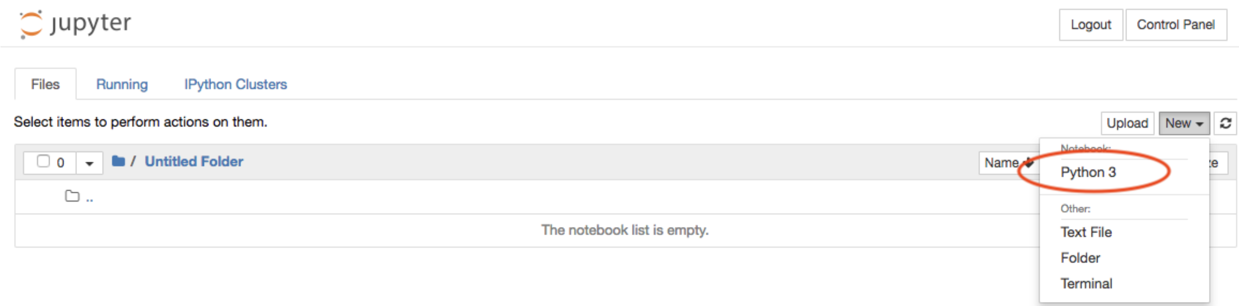

Figure 8: Navigate to `jupyterhub.wpi.edu/hub/login` and sign in with your WPI email address and password, choose an instance to spawn (either is fine) and create a new Python 3 file as shown here

We have set up a Jupyter notebook you may use. The website is https://jupyterhub.wpi.edu/hub/login.[1] There are many ways to learn Python, including reading a book, asking a friend, working through examples, or googling furiously when problems arise. We encourage you to discover which approach works best for you. Going forward this class will provide basic Python examples, but feel free to iterate upon the template we provide. What we provide is a stripped down version, and elaboration is encouraged. See this Github repository for our examples. We hope at the end of this term you will be able to add to your resume "Proficient in Python".

Jupyter uses a cell based system and evaluated variables carry over to the next cell. There are a few different types of cells, Figure 7 shows 2 kinds, the code cell, which we will be using most of the time, and the markdown cell, which you can use to add nicely formatted notes to you file.

[1] If you cannot log in please email WPI's IT department, and they will be happy to help polite students. The first thing they will tell you, however, is to check to make sure you don't have to change your password and try a VPN if you are off campus.

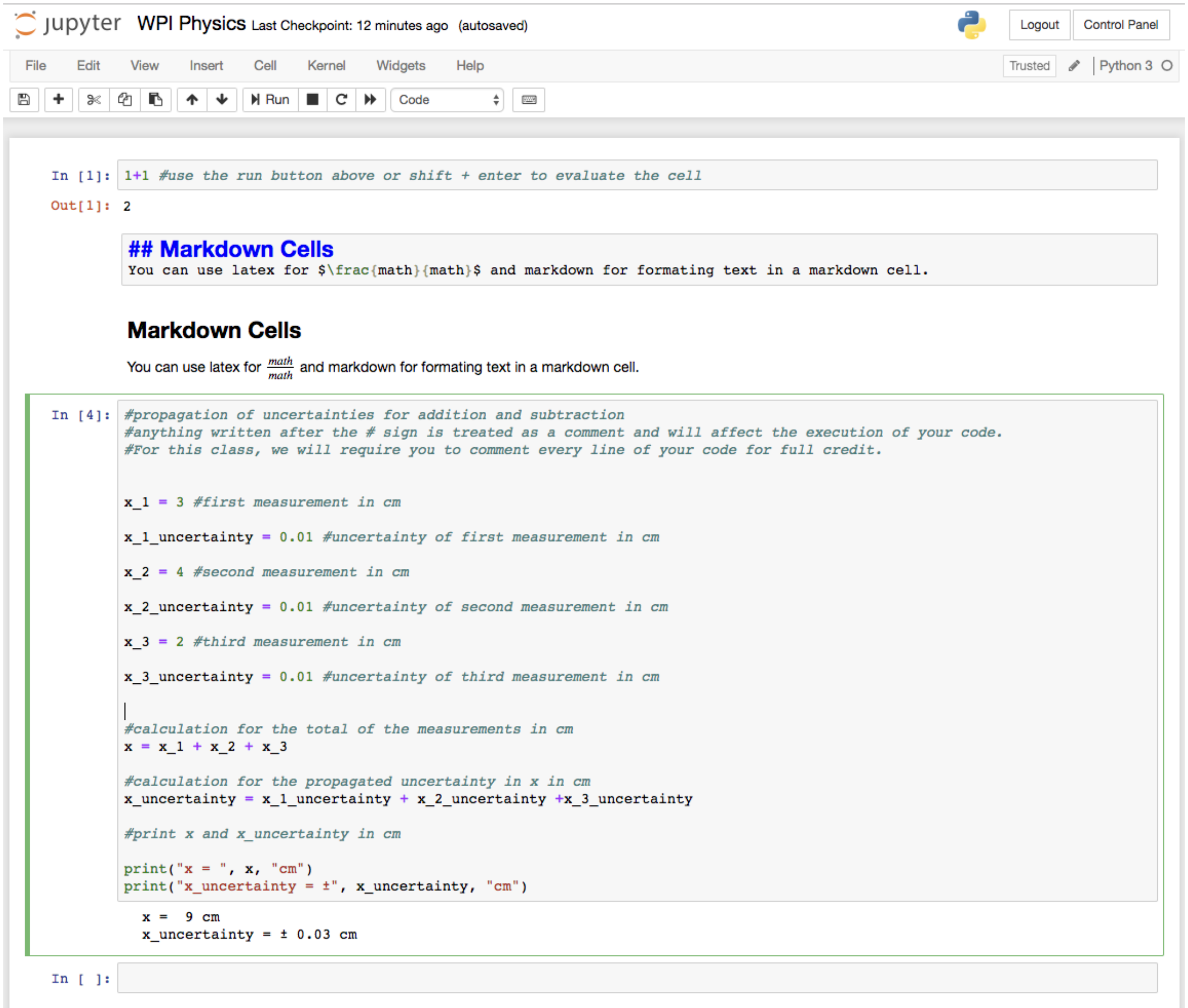

Figure 9: Above is the code that you could use use to propagate uncertainty for values that are added or subtracted. Always remember to comment your code.

If you prefer to work through a book or examples we recommend Mark Newman's book, which is available for free on his website [2]. Chapter Two is a basic introduction to the syntax for Python. Chapter Three covers graphs and visualizations, and we hope you will look into it if you learn best from a book. If you wish to get a head start in this class we recommend reading this book.

If you wish for a more advanced textbook there is a compilation of free online computational physics books here.

References

[1] Philip Ilten. The hitchhiker's guide to first year physics labs at ucd. 2010.

[2] Mark Newman. *Computational Physics with Python*. CreateSpace Independent Publishing Platform, 2012.